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ABSTRACT
The primary questions investigated are: Is it true that males excel in mathematical problem solving and, if so, when does this superiority develop? An examination of recent research showed that sex-related differences did exist, although small, even after controlling for mathematics background. Differences appeared in early adolescence and were found only with subjects of above-average ability and on problems whose content is spatial or sex-biased. Eliminating sex bias in tests eliminates or reduces differences. The remaining differences are probably involved with social attitudes toward problem solving as a male activity. (MP)

ARE MATHEMATICS PROBLEMS A PROBLEM FOR WOMEN AND GIRLS?

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International Women's Year in 1975 focused attention on improving the status of women. In this country women's demands for equality have led to identification of a number of target areas in which women's roles have been limited in the past: primary among these are the economic and intellectual activities of the nation. Educators in general and mathematics educators in particular are now beginning to address themselves to broadening and improving the economic and intellectual position of women.

In the economic sphere men far outnumber women in occupations requiring a high level of mathematical competence. Various causes for this imbalance have been hypothesized: sex bias in career counseling, discrimination in admission to specialized schools, and differences in sex-role socialization. In addition, differences in mathematical ability are often suggested as reasons (Carnegie Commission, 1973). Some have said that while girls may be better at computation, boys excel at mathematical reasoning (Glennon and Callahan, 1968; Jarvis, 1964; Maccoby, 1966). If this is true, mathematical reasoning could be the "critical filter" (Sells, 1973) in the scientific and technical job market, since in those occupations the application of mathematics to problems is valued more highly than computing skill. Furthermore, not all economic activity is job related. As women become more independent in buying and maintaining homes, cars, and other products, they need to be able to solve mathematics problems of a practical nature. The traditional female duties of providing food and clothing continue to pose mathematical problems to be solved.

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In the intellectual sphere the importance of problem solving is not to be underestimated. To quote George Polya (1962, p. v.), "Solving problems is the specific achievement of intelligence and intelligence is the specific gift of mankind [sic]: solving problems can be regarded as the most characteristically human activity." Furthermore, solving mathematics problems has been regarded as the essence of human problem solving; psychologists often use mathematics problems in their general problem-solving research (Berry, 1958, 1959; Carey, 1955; Milton, 1957, 1958; Simon and Newell, 1971; Sweeney, 1953). Mathematics educators themselves stress the value of teaching problem solving.

> Our instruction serves to develop the capacity of the human mind for the observation, selection, generalization, abstraction, and construction of models for use in solving problems in other disciplines. Unless the study of mathematics can operate to clarify and solve human problems, it has indeed only narrow value.
>
> Fehr, 1974, p. 27

Having recognized the importance of being able to solve mathematical problems, one should return to this question: is it true that males excel at mathematical problem solving? Before examining the research literature on that question, it would be well to adopt a precise definition of a mathematical problem.

> A mathematical problem is a statement which meets three conditions:
> (1) the statement presents information and an objective based on that information;
> (2) the objective or answer can be found by translation of the information into mathematical terms and/or application of rules from mathematical areas such as arithmetic, algebra, logic, reasoning, geometry, number theory or topology; and
> (3) the individual attempting to answer the question or attain the objective does not possess a memorized answer or an immediate procedure.
>
> Zalewski, 1974, pp. 4-5

The third part of the definition serves to set real problems apart from routine applications or exercises. To qualify for inclusion in this review a study must have used test items intended by their designers to measure mathematical behavior other than computation and items which seemed to this author to satisfy the definition.

A second question guided the organization of this review. If males as a group are better at solving mathematical problems than females, when does this superiority develop? In order to investigate that question the studies were grouped as follows: elementary; Grades 7 and 8; Grades 9 through 12; college and adult. In fact, since most mathematics tests for primary grades are computational, the elementary studies reported are from Grades 4 through 6. Whenever possible two additional refinements of the original question were investigated. Do the results depend on whether the content of the problems is algebra, geometry, or real-life situations? Are the results different for different ability groups?

Several of the studies which contributed most to this section of the review are longitudinal and a word needs to be said about their methodology. One is the National Longitudinal Study of Mathematical Abilities (NLSMA), probably the most intensive and extensive study in this area. Three different groups were tested: one in Grades 4 through 8, another in Grades 7 through 11, and the third in Grades 10 through 12. A content (number systems, geometry, algebra) by level of behavior (computation, comprehension, application, analysis) matrix was used to categorize the mathematics scales. Both application and analysis scales were included in this review, although the definition of analysis items seems closer to the definition of a mathematical problem. The study, designed to compare certain textbook series, involved primarily college-capable students. Another factor which should be considered in evaluating the results is that the sex-related differences reported were those remaining after removal of the variance due to verbal IQ, nonverbal IQ, and mathematics achievement. A second longitudinal study (Hilton & Berglund, 1974), whose results are reviewed here, measured the same students in Grades 5, 7, 9, and 11 using the Sequential Test of Educational Progress-Mathematics (STEP-Math) which the authors regarded as a measure of the ability to apply skills to problem solving. The sample was divided into an academic group and a nonacademic group according to what program they eventually pursued in high school, and results were analyzed separately by group.

In the NLSMA study of Grades 4 through 6 boys excelled on two out of three applications scales, both concerned with number systems, and on the only analysis scale, a geometry scale (Carry & Weaver, 1969). Hilton and Berglund found no significant differences in either fifth-grade group on STEP-Math. In a study using fifth-grade subjects Harris and Harris (1973) found no sex-related differences on either of the two cognitive abilities tests containing mathematical problems. Similarly no differences between boys' and girls' performances on an arithmetic reasoning test were found by Parsley, Powell, O'Connor, and Deutsch (1963). A second study (1964) by those authors indicated better performance by males on 12 subgroups and by females in 7 subgroups out of a total of 75 comparisons. In a study of sixth-grade students Jarvis (1964) found that boys of all ability levels surpassed girls in arithmetic reasoning. Clearly, although some differences have begun to appear in upper elementary school, the results are mixed.

Sex-related differences were more apparent in the studies reviewed using seventh- and eighth-grade students. Hilton and Berglund reported a difference in favor of boys on STEP-Math in the academic group. The NLSMA also gave STEP-Math to one group in seventh grade, categorizing it as an application test, and found boys' performance to be superior (McLeod & Kilpatrick, 1969). Sex-related differences in favor of boys were also found on all but one of the analysis scales and on the one application scale designed by NLSMA (Carry 1970; McLeod & Kilpatrick, 1969). The content of the scales on which differences were found was number systems and geometry; the scale on which none were found was an algebra scale. In a study of problem-solving styles in high-ability, eighth-grade subjects Kilpatrick (1967) found that although scores for boys and girls were about the same, girls used significantly more deduction and more equations. In the National Assessment of Educational Progress (NAEP) consumer math skills were measured by a test of problems given to 13-year-olds, 17-year-olds, and young adults ages 26 to 35. In the youngest group the boys' median was 1½% above the median of the total group and the girls' median was 1½% below (Ahmann, 1975).

With the exception of the NAEP all the studies discussed in this section in which sex-related differences were observed were conducted with students of above-average ability. There is another indication that overall superiority of boys in mathematical problem solving in Grades 7 and 8 may be due to superior performance of boys of high ability. In a study of mathematical precocity Stanley, Keating, and Fox (1974) found that in a sample of seventh- and eighth-grade students who volunteered for screening with the Scholastic Aptitude Test-Mathematics (SAT-M) boys far outperformed girls and the discrepancies increased with age. These results ought to be tempered by the observations of Donlon (1973) who studied the sex-related differences in performance item by item on both the verbal and mathematical sections of the SAT given in May 1964. Of the 60 items on the SAT-M 17 were found to refer to real world things. There were no female agents in these 17 items and, according to Donlon, there seemed to be a masculine tenor to the items. This was also the type of item on which the sex-related difference in performance in favor of males was the greatest.

Surveying the studies of high school students required additional caution because required mathematics courses are more often tracked and mathematics becomes elective in the upper grades. Good examples of this lack of control for number or type of mathematics courses taken are the Project Talent Survey (Flanagan, et al., 1964) and the NAEP (Ahmann, 1975) both of which found sex-related differences in favor of males. In all the other high school studies reviewed here the students were in the same mathematics class or track when tested.

Information on sex-related differences in the NLSMA were reported only for the college-preparatory group. At the applications level boys in Grades 9 through 11 excelled girls on 5 out of 12 geometry scales and the one algebra scale. At the analysis level their performance was superior on half the algebra and number systems scales; on the geometry analysis scales boys excelled on 6 of the 8 and girls on 2. (Kilpatrick & McLeod, 1971a, 1971b; McLeod & Kilpatrick, 1971; Wilson, 1972a, 1972b).

The impression of overwhelming evidence of male superiority on NLSMA mathematical problems solving tests should be tempered by limitations of the study due to sampling, statistical analysis, and problem content of the tests. The sampling restriction to upper-ability students was more severe in the high school data than in the junior high data. The statistical removal of variance

Table 1

Sex-Related Differences in Analysis Scales
National Longitudinal Study of Mathematical Abilities

Grade	Number Systems			Geometry			Algebra		
	Total	Boys a	Girls b	Total	Boys	Girls	Total	Boys	Girls
4									
5				1	1	0			
6									
7	2	2	0	2	2	0			
8	3	3	0	4	4	0	1	0	0
9				1	1	0	1	1	0
10				6	4	2			
11	2	1	0	2	2	0	2	1	0

a Number of scales on which boys' performance was significantly better.
b Number of scales on which girls' performance was significantly better.

Table 2

Sex-Related Differences in Applications Scales
National Longitudinal Study of Mathematical Abilities

Grade	Number Systems			Geometry			Algebra		
	Total	Boys a	Girls b	Total	Boys	Girls	Total	Boys	Girls
4	1	0	0						
5	1	1	0						
6	1	1	0						
7	1	1	0						
8	1	1	0						
9									
10				6	4	0	1	1	0
11				6	1	0			

a Number of scales on which boys' performance was significantly better.
b Number of scales on which girls' performance was significantly better.

due to verbal and non-verbal IQ and mathematics achievement may have left only a small fraction of the variance. Application of the ω^2 statistic (Hayes 1973) to three of the analysis scales given in Grade 11 showed that on each less than 1% of the variance was due to sex. With respect to problem content, sex-related differences in performance on the analysis scales appeared most numerous in the area of geometry, which may be related to the reported male advantage on spatial abilities (Bennett, Seashore & Wesman, 1973; Maccoby & Jacklin, 1974). One of the two geometry scales on which girls excelled was Structure of Proof, which appeared to require verbal rather than spatial skills. Finally, the content of the number systems problems for Grades 4 through 11 should be considered. Among these were all the problems about people. In virtually all cases in which sex of a person was specified, the person was male.

Evidence of the importance of sampling, statistical analysis, and problem content was found in other high school studies. Differences dependent on sampling of ability levels was evident in the Hilton and Berglund study where boys from the academic group scored significantly higher than girls in Grades 9 and 11, whereas in the nonacademic group boys scored higher than girls only in eleventh grade. Statistical techniques were used by Sheehan (1968) in a study of problem solving in ninth-grade algebra to change a slight (but nonsignificant) advantage of girls into a significantly difference in favor of boys by removal of the variance due to algebra aptitude and previous mathematics achievement and knowledge of algebra. In his high-ability, Swedish, high school students Werdelin (1961) found sex-related differences limited to two tests of geometrical problems. The importance of problem content was also demonstrated by Leder's (1974) study using mathematically parallel pairs of problems with stereotypically male and female settings. Tenth grade boys and girls both preferred the problems appropriate to their traditional sex-roles.

Studies of college students and adults are even more open to criticism for lack of control for previous exposure to mathematics. Very's (1967) study and the NAEP, both of which found males to be better problem solvers, can be criticized on this point. However, there is a significant group of interrelated studies of problem solving in college students in which previous mathematics training was controlled. After Sweeney's 1953 study in which sex-related differences in addition to those due to intellectual factors were found, the others investigated various other noncognitive sources of the difference. Carey (1955) found attitude toward problem solving to be a significant factor in males' better performance on the problem test. Moreover, following a treatment designed to improve attitude, women's problem-solving performance improved significantly, whereas men's did not. Milton (1957, 1958) and Berry (1958, 1959) investigated the relationship between the Terman-Miles masculinity-femininity index and mathematics problems similar to those used by Sweeney and Carey. In only one of the four studies was the correlation significant after the removal of the effects due to verbal and quantitative factors. In the 1959 study Berry used a number of other noncognitive measures and found that the only ones contributing to the remaining problem solving variance were two tests of spatial ability and Carey's attitude test--and this only for males. Milton also investigated the effects of problem content and found men superior at solving "masculine" but not "feminine" problems.

All of the studies reported thus far were done before 1975 and, with the exception of the college studies just described, were designed to study other areas besides sex-related differences in problem solving. Summarizing them is difficult. The sex-related differences may have been small but they did seem to exist, even after controlling for mathematics background. Differences appeared in early adolescence and may have increased with age until maturity. The pre-1975 studies indicate that sex-related differences may be found only with subjects of above-average ability and on problems whose content is spatial or sex-biased. Differences on sex-biased problems suggest that social pressures prevent females from solving problems as successfully as males. Since 1975 research has been done on problem solving that either concentrated on the areas identified above or at least showed an awareness of the issues involved with using sex as a variable.

Sex bias in item content of problem solving tests is the area in which results of recent studies have been most definitive. There are several ways of assessing such bias and eliminating it. Faggen-Steckler, McCarthy, and Tittle (1974) developed a technique for measuring sex bias in tests based on the ratio of male nouns and pronouns to female nouns and pronouns. They calculated the ratios two ways--both including and excluding such generic nouns as chairman, mailman and mankind. Using this procedure they examined eight standardized achievement test batteries among those most frequently used in public schools; among these batteries were the Sequential Tests of Educational Progress on which sex-related differences had been observed in the NLSMA and the Hilton-Berglund study discussed earlier. All eight batteries were sex biased in favor of males in varying degrees. It should be noted, however, that in this study entire test batteries were evaluated, not the mathematics tests in particular.

Another technique for trying to eliminate sex bias in problem solving tests is to treat each item as a unit. A study of seventh-grade students by the author (Schonberger, 1976) used a test constructed using the following technique. Whenever possible the problem was made neuter. For example, "Six girls belong to a basketball team" became "Six students belong to a basketball team." Where this was not possible, names and pronouns were changed so that there were equal numbers of male-acted and female-acted problems in each subtest. There were no significant sex-related differences between girls' and boys' performances on two of the three subtests or on the total test. The better performance by males on the third subtest was due primarily to one item which involved comparing shooting averages in a ball game, a task which may have been more familiar to boys than to girls. This one difference in favor of males was not more pronounced in the upper ability group.

The Romberg-Wearne Problem Solving Test (Wearne, 1976) which has concepts, applications, and problem solving subtests and has been used in several recent studies was also balanced by equating numbers of male-centered and female-centered items. Meyer (1976) used this test in a study of cognitive abilities and problem solving abilities of fourth-grade students; she found no significant sex-related differences. Fennema and Sherman also used the Romberg-Wearne test in their middle-school study (1978) and found sex-related differences in only one of the four areas of the city used in the study. In summary, these recent studies of children in Grades 4 through 8 suggest that when an effort is made to eliminate sex bias from the tests, fewer sex-related differences appear.

The elementary and middle school studies just reviewed focused primarily on the actors in the problems as a source of sex bias. However, the author's study showed that the content of items may also be a source of bias if the topic, such as sports, is more interesting or familiar to one sex than the other. McCarthy's (1976) study of problem solving using students in Grades 10 through 12 dealt with this aspect of bias. A group of students categorized each of a large battery of problems similar to those used on the SAT-M as masculine, feminine, or neutral. Another group of students were then tested with 26 of each type of item. Using a technique common in test construction, McCarthy computed the point-biserial coefficient for each problem for the males, the females, and the total group to identify the 26 items which best discriminated between high and low scorers in each group. Of the 26 best discriminators for girls, 14 had been categorized as feminine items, 2 as masculine, and 10 as neutral; of the boys best discriminators 11 were masculine, 6 were feminine and 9 were neutral. The distribution for the total group best discriminators was close to that for the boys: 10 masculine, 4 feminine and 12 neutral.

Twelve items appeared in all three groups of best discriminators, but performance by males and females differed significantly on the three tests.

Table 3

Comparison of Means in McCarthy's Study
(McCarthy, 1976, p.55)

	Male Means	S.D.	Female Means	S.D.
Total Group Discriminators	17.90	5.38	14.36	6.34
Male Group Discriminators	16.02	5.66	12.93	5.64
Female Group Discriminators	13.98	5.20	15.61	6.49

Females did best on the female group discriminators and least well on the male group discriminators. Male performance on female discriminators was better than female performance on male discriminators, and male performance on male discriminators was better than female performance on female discriminators, but the differences were certainly smaller than the male-female differences on the total group discriminators. This is important because under common test construction procedures the total group discriminators would have been used as the problem solving test.

So far the discussion of recent studies has focused on the sex of actors in the problem or on sex-role stereotyped interests such as sewing and cooking for females and business or sports for males. These types of problems were categorized as number systems problems by the NLSMA, which found them generally easier for boys as a group than for girls. The other type of problems on which males outperformed females in some of the earlier research was geometry problems. Two questions have guided recent research in this area.

1. Do males still outperform females on mathematical problems with spatial or geometric content?

2. If so, is the male advantage in problem solving related to male advantage on tests of visual spatial ability?

The author's (1976) study investigated the first question by constructing a problem solving test with three types of problems.

A. Problems in which the stimulus (presentation of the problem) is partly pictorial or which require spatial or geometric skills or knowledge for solution.

B. Problems with a completely verbal stimulus in which spatial skills (such as visualizing the situation or drawing a diagram) may be useful but are not necessary for solution.

C. Problems which appear to have no spatial content.

In the seventh-grade sample used in this study there were no significant sex-related differences in performance on Type A or Type B problems. The significant difference in favor of males on the Type C problems was due to sex-bias of one item dealing with sports as discussed previously.

According to recent studies by Meyer (1976) and by Fennema and Sherman (1978) as well as by the author, superiority in problem solving and spatial ability are not necessarily related. In Meyer's study of fourth grade students there was a sex-related difference in favor of males on the Space Relations test from the Primary Mental Abilities battery but no difference on the Romberg-Wearne Problem Solving Test. In the Fennema-Sherman middle school study there were no significant sex-related differences in the Space Relations Test of the Differential Aptitude Test, even in the area of the city in which differences in favor of males had been found on the Romberg-Wearne test. In the author's study five spatial tests were used including the DAT Space Relations test and a form board test, the type used by Meyer. Only on the form board test did boys excel, and this test was the least closely related to the problem solving measures of any of the five spatial tests. The question just asked about geometric problems and spatial ability have not been investigated with high school students in recent studies. Given the NLSMA results and similar findings by Donlon (1973) with respect to the SAT-M, it seems that further research at the high school level would be useful to see if females still perform less well on spatial or geometric problems.

If such research does find that females perform less well on certain types of questions, it raises important issues in the area of test construction. As Donlon pointed out, the male "advantage" of 40 points on the SAT-M data he studied could grow to 60 points if only real life subject matter items were used or diminish to about 20 points if only algebra-type items were used. If there are certain types of items on which males do better than females, is it justifiable to eliminate them? If there are certain types of items on which females do better, is it fair to increase their numbers? These are difficult questions to answer, and are ultimately related to the content validity of the test. While the author sees no difficulty in eliminating sports problems dealing with batting averages, the elimination of all spatial or geometric content from a test of mathematical problems seems illegimate. Whether or not different item formats weight test performance in favor of males or females should also be investigated.

McCarthy commented on another test construction issue, the possible sex bias in the point-biserial technique for selecting items from a pool which best discriminate between high and low scorers. She argued that if there are more males than females among the high scorers and more females than males among the low scorers, then the point-biserial technique selects items on which males do better than females. Indeed with her data the best discriminators for the total group were 10 masculine, 4 feminine and 12 neutral items. She experimented with different ways of eliminating this bias such as selecting the 9 best items in each of the masculine and feminine categories and the 8 best neutral items. She found the least difference in male and female performance by using only neutral items but decided that the restriction in content was unacceptable.

While most educators would agree that separate tests for males and females are not feasible, the technique of balancing a test with equal numbers of "masculine" and "feminine" items also can be questioned. Is it legitimate to perpetuate sex-role stereotypes by using problems in which girls cook, sew and lose weight while boys build, fish and buy cars? The author thinks not. However, the following test construction strategy offers a possible solution. As many items should be made neutral as possible without lowering the content validity of the test. The remaining set of items should be balanced with respect to male and female actors as well as with respect to stereotypically masculine and feminine content. However, there should be females with hammers and saws as well as males with pots and pans, and female cab drivers as well as male teachers.

Constructing sexually fair tests may not be sufficient to eliminate all the sex-related differences in problem solving performance. There were indications in the earlier research (Carey, 1955) that females' attitudes toward problem solving were inhibiting their performance. In a study by McMahon (McCarthy, 1976) students in Grades 6 and 10 and college freshmen were asked to predict their own success on scrambled word problems and arithmetic problems after being assured of their familiarity with the problems. Although there were no differences in males' and females' expectations of success on the word problems, females at all three ages significantly underpredicted their success on the arithmetic problems.

More recent research indicates that social expectations and pressures are probably still affecting women's performance. In Fennema's and Sherman's study the one area of the city in which males outperformed females on the problem solving test was the one in which sex-related differences were observed on six of the eight attitude measures. Hall (1976) studied high-ability high school students solving problems in groups of four and offered this observation.

> The constituency of a team appeared to affect its performance. For example, sexually mixed teams appeared to lose input from female members because of male dominance of conversation or assignment of a female to the role of recorder (secretary).
>
> Hall, 1976; p.55

However, a more positive note is that such social pressure may not be uniform across ethnic groups. Schratz (1976) observed a trend for white adolescence males to outperform white females in mathematical reasoning, but the trend was reversed for black adolescents.

In summary, the results of recent studies of sex-related differences in problem solving are both encouraging and useful. Efforts to eliminate sex bias in tests has eliminated or reduced the difference between male and female performances in problem solving. Although one study of seventh-grade students indicated that geometric or spatial content was no longer a stumbling block for females, studies of high school students in this area would be useful. The remaining differences are probably involved with social attitudes toward problem solving as a male activity. It is in this area of changing the attitudes of students of both sexes that teachers will have to be most tactful, most inventive, and also most reflective. The problem with problems has not disappeared entirely, but the changes that have occurred suggest that further change is possible. As mathematics educators we should commit ourselves to doing our part to enable women to participate fully in our mathematical society.

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